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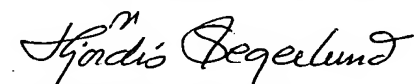
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Description

Acoustic Analysis of Gas Mixtures

5 The present invention relates to an acoustic gas analyser of the type described in the pre-amble to Claim 1.

In medical and clinical settings it is useful to be able to measure accurately the composition of respiratory
10 (inspiration and/or expiration) gases or changes therein since these can provide, for example, valuable information on patient metabolic conditions. This is particularly the case during the provision of mechanical respiratory aid to a patient where knowledge of the relative and absolute amounts
15 of oxygen and carbon dioxide within the expiration gas may be used to provide information on the metabolisation of oxygen as well as respiratory function. Moreover, knowledge of the oxygen/nitrogen ratio in an inspiration gas is useful for controlling or monitoring the provision of respiratory aid
20 using a mechanical breathing aid such as a ventilator, respirator or anaesthetic machine.

Gas analysers are known, for example from WO 92/03724 and from US 5247826, for acoustically analysing the ratios of a
25 mixture of gases comprising two known gases, such as the oxygen/nitrogen ratio in a breathing gas to be supplied to a patient by a mechanical breathing aid. The oxygen concentration or changes therein can then be determined. The known analysers utilise the physical phenomenon that acoustic
30 waves travel with different velocities through different gases. It is well known that the acoustic velocity, Vg, within a gas mixture can be described by an equation of the form:

$$V_g = \sqrt{\frac{C_P * R * T_g}{M * C_v}} \tag{1}$$

35 C_P and C_v are the specific heat capacities of the gas mixture at constant pressure and volume respectively; M is the molecular weight of the gas mixture; R is the universal gas

constant; and Tg is its absolute temperature. Thus for a gas mixture at a known temperature, Tg, the acoustic velocity, Vg, in the mixture can be used to provide a measure of the relative concentrations of the constituents of the gas.

5

In general, the known acoustic gas analyser comprises an ultrasonic velocity meter having a transducer arrangement adapted to transmit ultrasound energy along an acoustic path through a gas mixture to be analysed within a measurement

10 cell or a section of a flow conduit containing the flowing gas mixture and to receive the so transmitted energy; a temperature probe disposed to monitor the gas temperature at a point within the cell or section and a calculator for calculating the acoustic velocity, Vg, of the ultrasound from

15 signals received from the velocity meter and for employing this velocity together with the temperature reading from the probe in a determination of compositional information for the analysed gas mixture based on the equation (1) above.

20 In order to determine the instantaneous composition of the gas mixture it is therefore necessary to know simultaneously the temperature of the gas and the acoustic velocity in the gas. However it is often the case that the time constant of the temperature probe is long compared with that of the

25 ultrasonic transducer arrangement. The temperature probe may then provide a time delayed picture of the actual temperature within the gas. This is particularly true where the gas undergoes temperature changes that are more rapid than the time constant of the temperature probe. A simultaneous

30 measurement of the acoustic velocity and the temperature can therefore produce a small temperature error which will result in incorrect compositional information being determined. This can be a problem when the analyser is employed in the determination of respiratory gas compositional information

35 since rapid gas pressure changes that normally occur within a ventilator system will result in temperature changes that may be faster than the time constant of the temperature probe.

According to the present invention there is provided an acoustic gas analyser as described in and characterised by the present Claim 1. By temporally adapting the signal

5   provided by the acoustic velocity meter to substantially match that provided by the temperature probe then errors caused by the above mentioned time constant may be considerably reduced.

10   Usefully, the signal from the acoustic velocity meter may be passed through a filter designed to subject the velocity related signal to a temporal amplitude variation dependent on the probe time constant.

15   A recursive filter, for example a digital filter, having characteristics selected to provide the desired temporal variation may be advantageously employed as the filter.

An exemplary embodiment of the present invention will now be
20   described with reference to the drawings of the accompanying figures, of which:

Fig. 1 shows a schematic block representation of an acoustic gas analyser according to the present invention;

25

Fig. 2 shows characteristic temporal response curves for the acoustic velocity meter and the temperature probe of the analyser of Fig. 1 (a) before adaptation (b) after adaptation of the output of the velocity meter.

30

Considering now the acoustic gas analyser 2 represented in Fig. 1. A gas flow conduit 4 may, as illustrated in the present embodiment, be a measurement cell having coupling members 6,8 at opposite ends for establishing a releasable
35   connection with an external pneumatic circuit (not shown) of a patient ventilator system or may be an integral section of such a pneumatic circuit. An ultrasound transducer

arrangement 10 is located with respect to the conduit 4 so as
to be able to emit ultrasound energy into and detect emitted
ultrasound after its transmission along a path 12, through a
gas to be analysed within the conduit 4.

5

In the present embodiment the ultrasound transducer
arrangement 10 comprises a cooperating ultrasound transmitter
10a and receiver 10b located on a same side of the gas flow
conduit 4. An ultrasound reflector 14 is also provided in the
10 present embodiment and is disposed generally opposite the
transducer arrangement 10 to reflect ultrasound from the
transmitter 10a back towards the receiver 10b. It will be
appreciated that the ultrasound transducer arrangement 10 can
be realised in a large number of different ways whilst
15 maintaining the basic functionality of emitting ultrasound
into and detecting ultrasound transmitted through gas within
the conduit 4 and that any one of these ways may be employed
within the analyser 2 without departing from the invention as
claimed.

20

A meter unit 16 is operably connected to the transmitter 10a
and receiver 10b to form an acoustic velocity meter 18. The
meter unit 16 is configured to operate in the present
embodiment in a known manner to control the transmitter 10b
25 to emit a pulse of ultrasound energy at a known time and to
measure the time, t, taken for the emitted pulse to traverse
the path 12 through gas within the conduit 4 and be received
at the receiver 10b. In the present embodiment the meter unit
16 comprises a microprocessor device which is programmed to
30 determine in a known manner an acoustic velocity V from the
time, t, and a known length, L, of the path 12 and to provide
a first output signal indicative of the so determined
velocity V. The meter unit 16 is itself connected to a
calculations unit 20, such as may be realised by a suitably
35 programmed microcomputer, and which in the present embodiment
is further configured to provide command signals to the meter
unit 16 to initiate the transmission of the ultrasound pulse

at a known sampling rate (typically of the order of a few
milli-seconds).

A temperature probe 22 is provided as part of the analyser 2
5   and has a sensor head 24 disposed to measure temperatures of
gas internal of the gas flow conduit 4, preferably proximal
or in the acoustic energy transmission path 12. The
temperature probe 22 is configured to provide a second output
signal to the calculations unit 20 which is indicative of the
10   temperature measured by the head 24. Because the temperature
probe 22 has a relatively long measurement time constant the
temperature measured by the head 24 may or may not be the
actual temperature, Tg, of the gas within the conduit 4 at
which the determination of the acoustic velocity was made.
15   The calculations unit 20 is programmed to utilise in a known
manner the temperature measured by the head 24 and the
velocity values to determine compositional information about
the gas within the conduit 4 based on the equation (1) above.

20   It is well known that the sensor head 24 requires a finite
time to equilibrate with its surroundings. The change with
time, t, of the temperature measured by the probe 22 as the
head 24 comes into equilibrium has a characteristic form
defined by the predetermined probe time constant, as is
25   illustrated by the broken-line temporal response curves 26 in
Fig 2(a) and (2b).

Also shown in Fig. 2(a) is a characteristic temporal response
curve of the acoustic velocity meter 18 which is illustrated
30   by the solid curve 28. As can be seen the acoustic velocity
meter 18 responds substantially instantaneously to provide an
output being the actual acoustic velocity, Vg, in the gas
within the conduit 4 at the temperature Tg.

35   The meter unit 16 operates to initiate acoustic velocity
measurements at a known sampling rate (represented by the
continuation of the solid curve 28 from the time t0) and

provides an output which responds substantially instantaneously to temperature changes (represented by the vertical rising edge of the solid curve 28 at time t0). In the present embodiment the above mentioned characteristics of

5   the meter unit 16 are exploited to determine a time t0 when a perturbation occurred. To this end the meter unit 16 is further adapted to compare successively measured acoustic velocities for changes in amplitude of a level indicating a temperature change in the gas within the conduit 4. The time

10 t0 can therefore be determined with an accuracy which is dependent on the sampling rate of the velocity meter 18. A signal indicating a detected temperature change is then output from the meter 18.

15 With reference now to Fig. 2(a), generally a determination of compositional information will be made within the calculations unit 20 at a time t1 after a perturbation (t0) in the temperature of gas within the conduit 4 has occurred. Owing to the relatively long probe time constant associated

20 with the temperature measurements made by the probe 22 a temperature measurement, Tt1, which is passed to the calculations unit 20 at the time t1 will differ from the actual temperature Tg of the gas at that time t1. The manner in which this temperature Tt1 differs is dependent on the

25 probe time constant and has a form shown generally by the broken-line curve 26. A velocity measurement passed to the calculations unit 20 from the velocity meter 18 at the time t1 will be, as mentioned above, a true representation of the velocity Vg of sound in the gas at that time t1.

30

The time dependent error in temperature measurement will result in errors in compositional information determined within the calculations unit 20 based on the equation (1). The magnitude of these errors being dependent on the

35 difference between the temperature, Tt1, measured by the sensor head 24 at that time t1 and the actual temperature Tg of the gas.

Returning to Fig. 1, a signal processor 30 is provided as part of the analyser 2. This is configured to temporally adapt the output from the velocity meter 18 to that output
5   from the temperature probe 22 before it is passed to the calculations unit 20. In the present embodiment the signal processor 30 operates to adapt the measurement signal output from the acoustic velocity meter 18 to mirror the output from the probe 22 and to provide a temporally varying amplitude
10   signal, Vt, for use within the calculations unit 20 as a measure of the acoustic velocity Vg within the gas in the conduit 4. The adaptation is selected such that the amplitude of the signal Vt which is output from the processor 30 has a temporal response curve substantially that of the amplitude
15   of the temperature signal from the probe 22. That is, the signal processor 30 operates to make it appear to the calculations unit 20 that the velocity meter 18 reacts as slowly to thermal change as does the temperature probe 22. This is illustrated by the solid curve 32 in Fig. 2(b).
20

To this end the signal processor 30 can be conveniently configured as a known recursive digital filter, having a filter constant, K, selected to achieve the desired temporal response for the output signal and in the present example
25   operates according to an algorithm of the form:

REPEAT:

$$Vt = \frac{Vold * (K-1) + Vg}{K}$$

$$Vold = Vt$$

30   UNTIL t = t1

Where Vg is the "unfiltered" velocity measured by the acoustic velocity meter 18 at the fixed and known sampling rate. The signal processor 30 is, in the present embodiment,
35   configured to receive the output from the meter 18 which indicates that a perturbation in the temperature of the gas has occurred and which is employed in the processor 30 to

initiate (time t0) the filtering of the velocity signal according to the algorithm above.

The constant K may be selected by a repeated comparison of the time dependent form of the output from the signal processor 30 with that from the temperature probe 22 and varying the value of K until a significant match is achieved. This may be done manually or automatically, using for example the calculations unit 20 to perform the comparisons on digital data sets representing the signals from the processor 30 and from the probe 22.
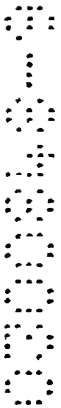
It will be appreciated that whilst the meter 16; the calculations unit 20; the probe 22 and the processor 30 have all been described as being separate units some or all of the functionality of some or all of these units may be combined in a suitably programmed microprocessor device fitted with appropriate known interface electronics without departing from the invention as claimed. Moreover, other constructions of filter, digital or analogue, may be provided using known constructional techniques to achieve the generation of a filtered signal having the desired form.

Claims

1. An acoustic gas analyser (2) comprising an acoustic
velocity meter (18) arranged to provide a first output (Vg)
5 dependent on a detected transmission of acoustic energy
through a gas to be analysed; a temperature probe (22) having
a probe time constant and arranged to provide a second output
(Tt) indicative of a measured temperature of the gas; and a
calculations unit (20) configured to receive the first (Vg)
10 and the second outputs (Tt) and to determine compositional
information of the gas therefrom c h a r a c t e r i s e d   i n
t h a t   the analyser (2) further comprises a signal processor
(30) configured to temporally adapt the first output (Vg)
dependent on the probe time constant and to provide a
15 temporally adapted first output (Vt) for use as the first
output within the calculations unit (20).

2. An acoustic gas analyser as claimed in claim 1
c h a r a c t e r i s e d   i n   t h a t   the signal processor (30)
20 comprises a filter arrangement adapted to receive the first
(Vg) output and to induce a time dependent amplitude
variation therein dependent on the probe time constant.

3. An acoustic gas analyser as claimed in claim 2
25 c h a r a c t e r i s e d   i n   t h a t   the filter arrangement of
the signal processor (30) comprises a recursive filter having
a filter constant (K) selected to provide the temporally
adapted first output (Vt) having a time constant
substantially that of the probe time constant.
30
4. An acoustic gas analyser as claimed in claim 3
c h a r a c t e r i s e d   i n   t h a t   the recursive filter is a
digital filter.

35

Abstract

Acoustic Analysis of Gas Mixtures

An acoustic gas analyser (2) comprises an acoustic velocity meter (18) arranged to provide a first output dependent on a detected transmission of acoustic energy through a gas to be analysed; a temperature probe (22) having a probe time constant and arranged to provide a second output indicative of a measured temperature of the gas; and a calculations unit (20) configured to receive the first and the second outputs and to determine compositional information of the gas therefrom. A signal processor (30) is connected between the acoustic velocity meter 18 and the calculations unit 20 and is configured to temporally adapt the amplitude of the first output from the meter 18 in a manner dependent on the probe time constant and to provide a temporally adapted first output for use as the first output within the calculations unit (20).
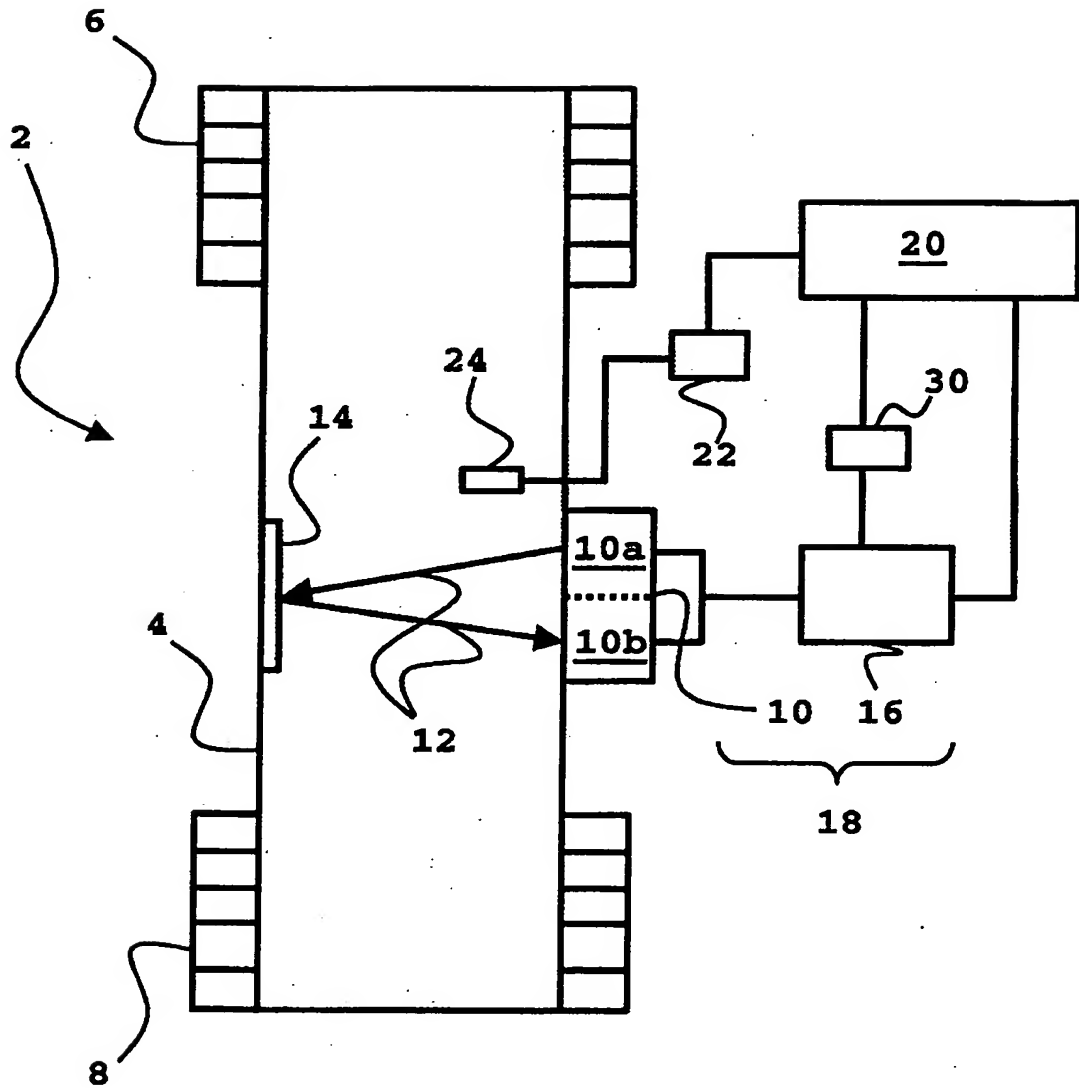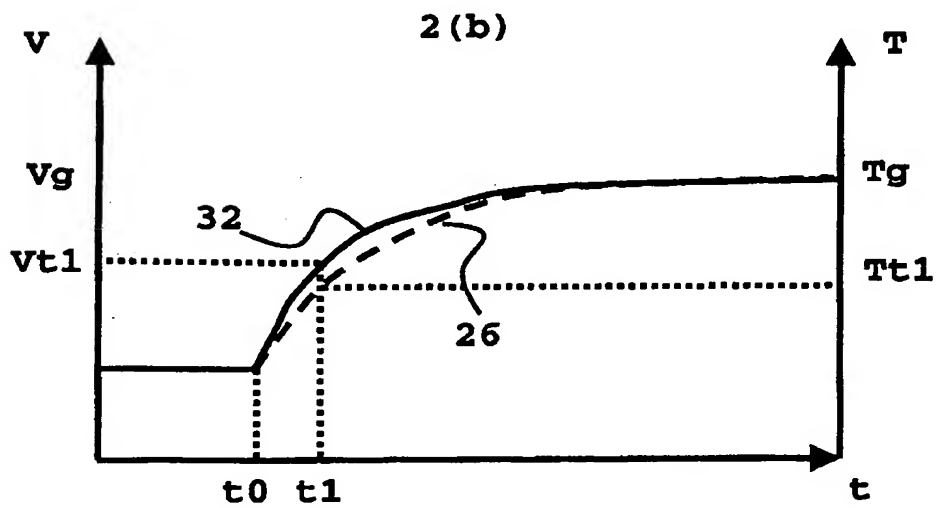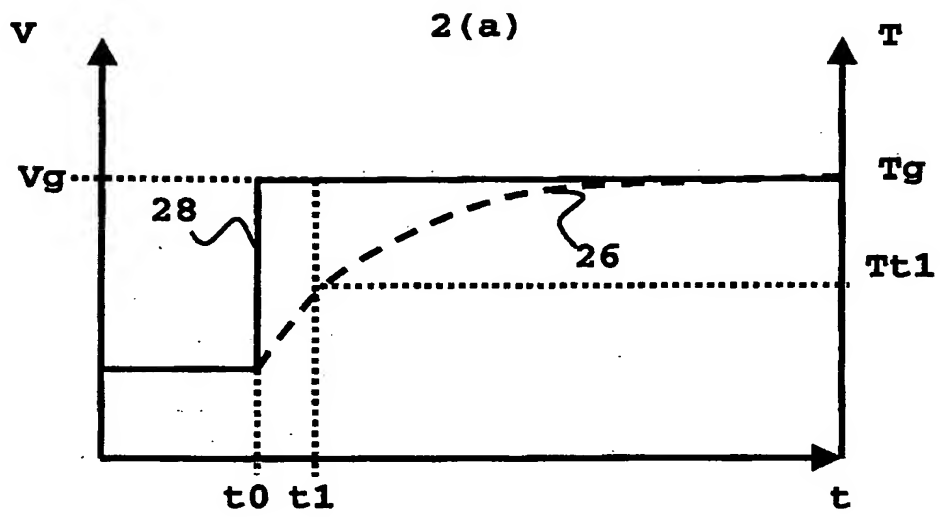
Fig. 1

Fig. 1

Figs. 2